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Analysis of Land Cover Changes of a Cerrado (Tropical Savanna) Area in the Centre-West of Brazil

Análise das Mudanças da Cobertura do Solo de uma Área de Cerrado (Savana Tropical) no Centro-Oeste do Brasil

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Resumo

O objetivo do presente trabalho foi produzir uma análise multitemporal da cobertura do solo em uma área no centro-oeste do Brasil, em duas diferentes épocas, em 1966 e 2001, utilizando uma imagem de satélite e uma carta topográfica em ambiente SIG (Sistema de Informações Geográficas). A carta de cobertura do solo de 1966 foi obtida pela vetorialização da carta topográfica SE-22-Y-A-V (IBGE), enquanto que a carta de cobertura do solo de 2001 foi obtida através de uma classificação automática supervisionada da imagem do satélite Landsat 7 ETM+ órbita/ponto 224/073 de agosto de 2001. A análise mostrou as alterações da cobertura natural para antrópica. Em 1966, a cobertura natural representava 90% ou mais da área estudada (principalmente por cerrado sentido restrito e formações florestais), enquanto que em 2001, a cobertura natural havia diminuído para 24%, sendo substituída principalmente por áreas de agricultura e pasto.
Palavras-chave: Cobertura do solo; Cerrado; Imagens de satélite; Análise multitemporal

Abstract

The objective of the present work was to carry out an analysis of the land cover of an area in the centre-west of Brazil, at two different times, in 1966 and 2001, using a satellite image and a topographic map, in the Geographic Information System (GIS) environment. The 1966 land cover map was obtained by vectorizing the SE-22-Y-A-V topographic map (IBGE), while the 2001 land cover map was obtained from supervised automatic classification of the Landsat image ETM+ satellite orbit/point 224/073 of August 2001. The analysis showed alterations from natural cover to anthropogenic. In 1966, natural cover was 90% or more (principally true cerrado and forest), while in 2001, natural cover had decreased to 24%, being replaced by arable land and primarily grassland.
Keywords: Land cover; Cerrado; Satellite images; Temporal analysis

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1 Introduction

The Cerrado biome is located principally on the Central Highlands of Brazil, and is the second largest biome of the country, after the Amazon rainforest, occupying an area of more than 2,000,000km^2, about 23% of the Brazilian surface area. This biome is the vegetation complex of tropical seasonal forest/ savanna, related to that found in the dry tropics of Africa, Asia and Australia (Ribeiro & Walter, 1998). The altitude varies from 300m to more than 1,600m above sea level.

The vegetation of the Cerrado presents physiognomies encompassing forests and shrubland formations. Present land cover of the region is commonly divided into five principal forms. "Open grassland" and "scrubland" are characterized by the predominance of grasses, and differ by the fact that the latter possesses sparse bushes. This scrubland (not to be confused with the shrubland landcover class of Sano *et al.* (2010)) may represent a transitional form between "open grassland" and "cerrado" (see below), in which the vegetation of the latter is regenerating. When the woody layer becomes more dense, and some trees are present, the form is termed "sparse cerrado", and, with the presence of trees reaching 10m in height, "typical cerrado". "Dense cerrado" is characterized by the presence of even taller trees, as well as a well-developed grass layer, and sparse bush vegetation (Ribeiro & Walter, 1998). Other forms, such as forest and wetland, represent the remaining area. In the present study, we have used the term "true cerrado" for the three forms of "cerrado" listed above, corresponding most closely to the shrubland class of Sano *et al.* (2010).

Habitat fragmentation and land conversion by humans for agricultural purposes are constant threats to conservation of biodiversity in the Cerrado biome. These landscapes dominated by agricultural activities have become dynamic mosaics, which are formed by different land uses (Carvalho *et al*., 2009).

Beginning in the 1970´s, large-scale agricultural development of the Central Eastern Plateau has lead to the removal of native vegetation (Silva *et al.*, 2006). For example, by the year 2005, a total of 43% (7% being floodplain and 93% upland) of the Upper Paraguay Basin located within the State of Mato Grosso had been deforested, with 69% of this having occurred by 1992 (Longhi *et al.*, 2006). This activity has resulted in extreme degrees of soil erosion and elevated levels of sediments entering the streams and rivers of the region (Paranhos Filho *et al.*, 2003; Carvalho *et al.*, 2005), causing flooding, restricted navigation, and destruction of aquatic communities (Ferreira *et al.*, 1994; Wantzen, 1998; Galdino *et al.*, 2006). Machado *et al*. (2004) have estimated that the Cerrado Biome could be completely destroyed by 2030.

Analysis of satellite images and topographic maps has been found to be a powerful tool in the documentation of such temporal changes in soil cover (Gordon, 1980; Disperati *et al.*, 1998; Longhi *et al.*, 2006; Sano *et al*., 2010). Research involving the establishment of the relationships between the spectral signatures of soil cover and conventional phytophysionomic keys for the Cerrado biome was initially carried out by Paranhos Filho (2000). In the present study, the research approach of Paranhos Filho (2000) was used to analyze changes in land cover of an area in the centre-west of Brazil, between two different dates, in 1966 and 2001, using a topographic map and a satellite image.

2 Study Area

The study area occupies part of the Costa Rica municipality and spans the division between the two main hydrographic basins (Rivers Paraguay and Parana) of Mato Grosso do Sul State, in the centre-west of Brazil (Figure 1). Note that, currently, in the study area there are two protected areas, the Parque Natural Municipal Salto do Sucuriú and Parque Natural Municipal da Laje, both considered by PROBIO (Project for the Conservation and Sustainable Use of Brazilian Biological Diversity - Ministry of Environment) as priority areas for conservation (Paranhos Filho *et al.*, 2006).

3 Methods

The Costa Rica topographic map (1:100,000 map articulation: SE-22-Y-A-V) (IBGE, 1978) was scanned and the digital file corrected geometrically and geographically coded to preclude deformations, using Erdas Imagine software (Erdas, 1997). During this process, the correction error reached a maximum of 10m.

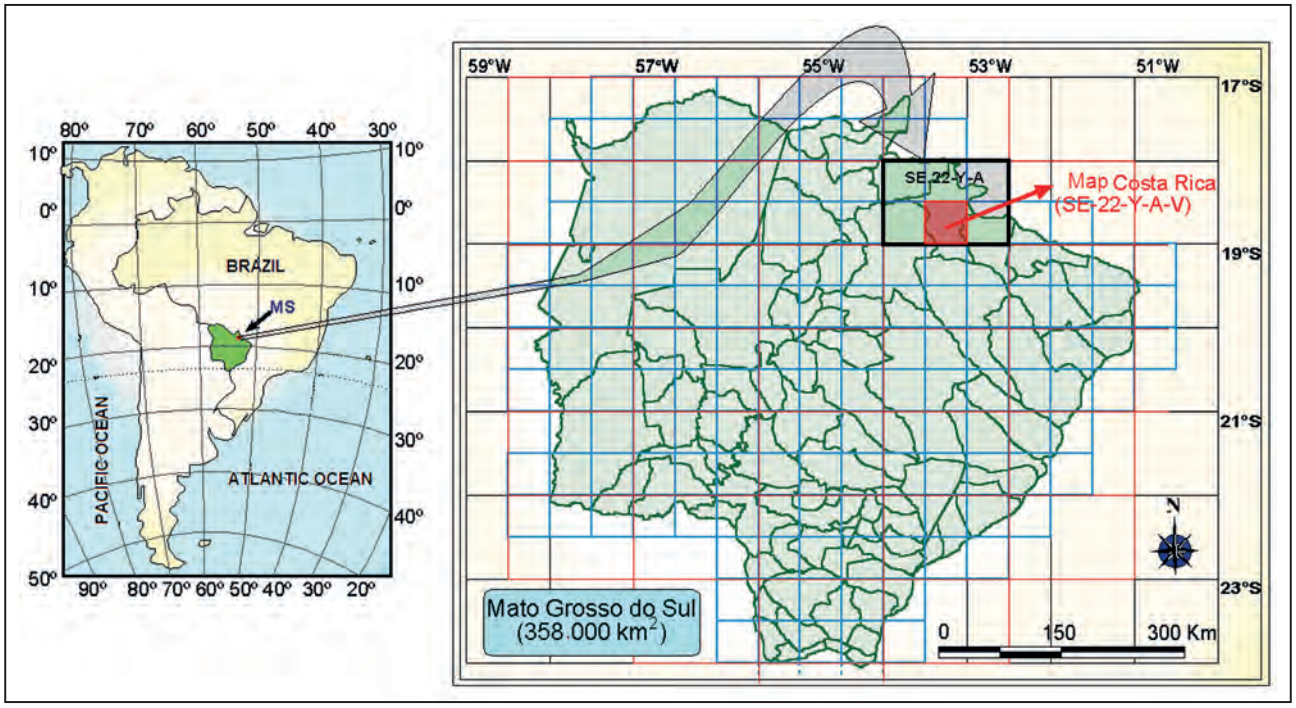

Figure 1 Localization of the study area (in red).

The map was exported to GeoTiff format and vectorialized using Macromedia FreeHand (Macromedia, 2000) and Avenza Mapublisher (Avenza, 2000) following the methodology proposed by Paranhos Filho (2000). The working technique in FreeHand is analogous to the utilization of aerial photographs and overlays, with the different levels of information, such as hydrographic data or land cover, being digitized in different layers, facilitating edition and analysis.

The Landsat 7 satellite image (ETM+ sensor), path row 224/073 of August 10, 2001 (Landsat 2001) was geometrically corrected and geocoded (UTM projection, Corrego Alegre datum, zone 22) on the same coordinate system of the IBGE map.

The image was classified automatically, in supervised mode (maximum likelihood algorithm) and accuracy verified by the algorithm "Accuracy Assessment" from Erdas Imagine software (Erdas, 1997) based on the Kappa index The spectral signatures proposed by Paranhos Filho (2000), and the classification keys for the Cerrado physiognomic types proposed by Ribeiro & Walter (1998) were used, in conjunction with verification in the field (see below). These relations between the Landsat spectral signatures and the land cover classes, as determined by Paranhos Filho (2000), are shown in figures 1-14 (Supplementary Material).

The classified image was reduced to coincide with the limits of the topographic map of 1:100,000, thus producing a soil cover map. Using this map, a legend was elaborated based on the scheme proposed by Paranhos Filho (2000).

For the actual temporal analysis, a comparison was made between the soil cover maps of 1966 and 2001, with the results being expressed in percentages.

Three field trips were made, the first from 16 to 18 November 2003, the second on 23 February 2004 and the third from 3 to 4 April 2004. On these trips, photographs of the different phytophysiognomies and classes of soil cover were taken with a digital camera, and the Global Positioning System positions, as well as the geographic coordinates and Universal Transverse Mercator Projection values of these points were obtained. These results were then compared to the spectral signature results to confirm the effectiveness of the latter in identifying the land cover class.

4 Results and Discussion

The land cover map of 1966, obtained from Costa Rica topographic map, has 4 classes (forest, true cerrado, wetland and grassland) according to

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the official data (IBGE, 1978), which were generated from aerial photographs from 1966. The land cover map of 2001, obtained from Landsat 7 satellite image, has 14 classes, which are fully comparable to the classes of topographic map. In the present work these classes were reinterpreted in just two classes, natural and anthropogenic land cover.

The land cover maps of 1966 and 2001 are shown in Figure 2. Tables 1 and 2 show the area in hectares of each class of land cover for the two years. The automatic supervised classification was 85% accurate.

Soil cover	Area (ha)	%
True cerrado	226041.41	77
Forest	34277.33	12
Wetland	1616.50	1
Grassland	26780.69	10
Total area	291715.94	100

Table 1 Soil cover in 1966, expressed in hectares and in percentages.

Comparison between the soil covers of 1966 and 2001 is possible even though the keys are different between years. This is because the comparison is being made at the level of natural versus anthropogenic, and, in 1966, natural cover types (true cerrado, forest and wetland) are described as in 2001. In the present study, areas of natural vegetation are considered to be those covered by true cerrado and forest, even if secondary, as well as wetlands. In our study, we distinguished four types of grassland (Table 2), as well as scrubland (which can be considered as true cerrado regenerating from grassland). All these classes were considered to be anthropogenic, in contrast to Sano *et al.* (2010) who made the distinction between natural and anthropic grassland (pastureland).

Classes of soil cover	Area (ha)
1 - Arable1	209.07
2 - Arable2	2917.07
3 – Dry and Riparian forest	4507.20
4 – Open forest (“Cerradão”)	8638.38
5 – True cerrado	52616.90
6 - Open grassland	56356.90
7 - Dry/tall grassland	6652.17
8 - Dry/low grassland	14797.04
9 - Humid grassland	30140.30
10 - Scrubland	109532.00
11 – Lakes and other lentic water-bodies	62.73
12 – Rivers	538.56
13 – Wetland	3948.03
14 - Urban	799.36
Total area	291715.71

Table 2 Classes of soil cover in 2001, expressed in hectares.

In the 1966 map, it is not possible to identify secondary vegetation. Using the images, such interpretation is difficult, principally when the time interval between the images used is large.

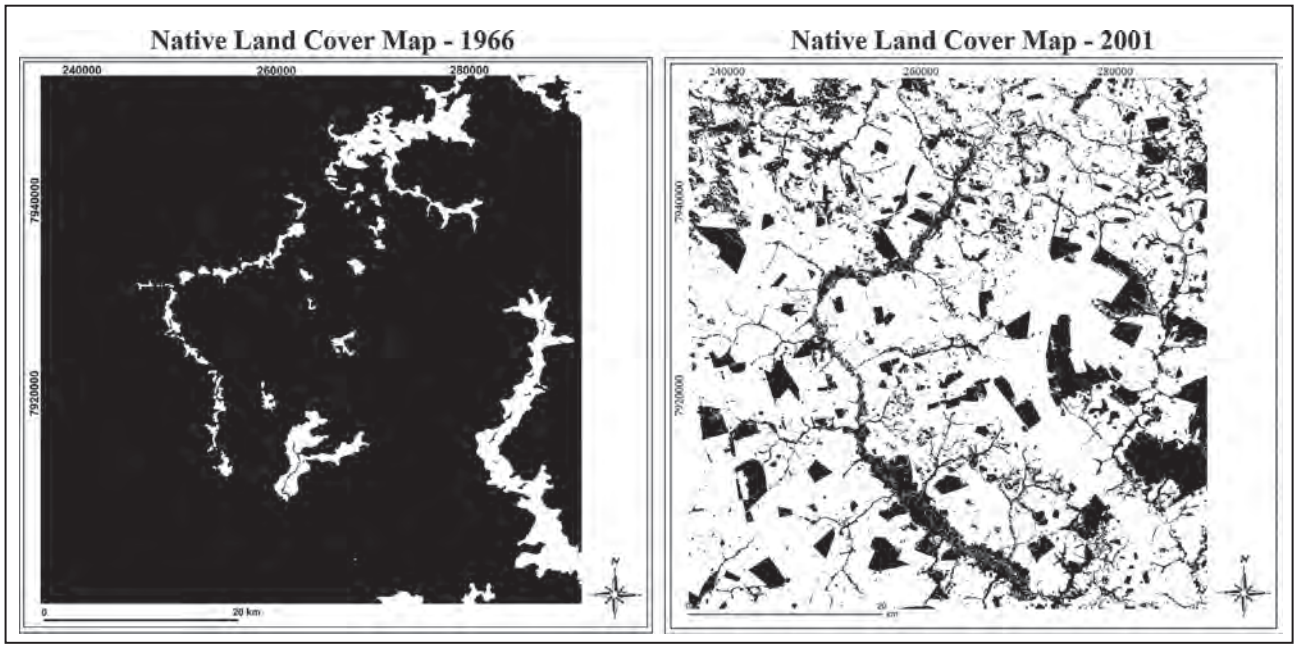


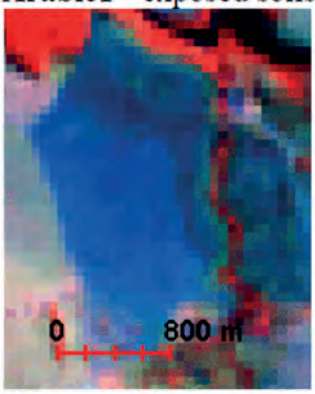
Figure 2 Comparison of natural (in black) and anthropogenic land cover (in white) between 1966 (left) and 2001 (right) in study area (Costa Rica topographic map 1:100,000).

In 1966, natural cover was 90%, with the remaining 10% being classified as grassland (Figure 2; Table 1). However, there is a strong coincidence between the spatial distribution of this grassland and the wetlands of the Sucuriu River, identified in the satellite image, perhaps suggesting incorrect classification in 1966. In 2001, natural cover was 24% (18% true cerrado, 4.5% forest and 1.5% wetland), and anthropogenic areas were 76%, the latter consisting of arable land, grassland and scrubland (Figure 2, Table 2). For 2002, Sano *et al.* (2010) found the principal land cover class in Mato Grosso do Sul to be pastureland. Thus, the area has suffered considerable modification between 1966 and 2001. The principal human activities causing such alterations were cattle rearing and the cultivation of seasonal crops (Harris *et al.*, 2005). The areas occupied by cattle rearing, consisting of new and mature grassland as well as scrubland, were predominant.

Analysis of satellite images and topographic maps in the GIS environment is a powerful tool for quantifying changes in soil cover and land use. Furthermore, the establishment of the relationships between the spectral signatures of soil cover and conventional phytophysionomic keys for the Cerrado biome permits analyses of great sensitivity to be carried out in the region (Paranhos Filho, 2000). Such an approach should be of importance for future studies of the present nature, as well as in research on other topics, such as habitat fragmentation and wildlife preservation (Lindenmayer & Fischer, 2006; Carvalho *et al.*, 2009).

5 Supplementary Material

Arable1 - exposed soils with red colour. Usually arable.

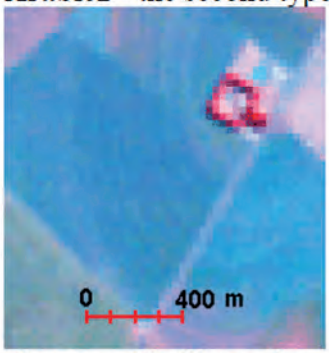


Photographic illustration (November, 2003).

Example of Arable1 spectral class, Landsat scene (ETM+ sensor), 224/073 path/row, R4 G5 B3 composite, August 2001.

Figure 3 Relationship between the Landsat spectral signature and the land cover class Arable1.

Arable2 - the second type of exposed soils with red colour.

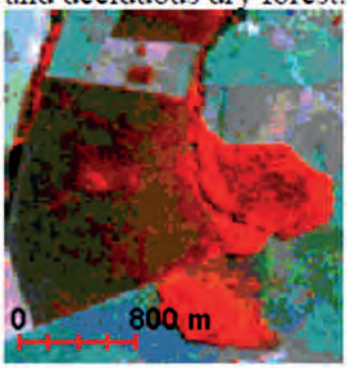


Photographic illustration, on both sides of the road (November, 2003).

Example of Arable2 spectral class, Landsat scene (ETM+ sensor), 224/073 path/row, R4 G5 B3 composite, August 2001.

Figure 4 Relationship between the Landsat spectral signature and the land cover class Arable2.

Dry forest - spectral class included in the dense forest and riparian forest (gallery forest) type of Ribeiro & Walter (1998). The dry forest has no association with water bodies, occurring on watersheds where the soils are rich in nutrients. According to the soil type, flora composition and extent of leaf fall during the dry season, the dry forest is divided into three sub-types: evergreen dry forest; semi-deciduous dry forest (the most common) and deciduous dry forest.



Dry forest - Landsat 7, ETM+, false colour composition RGB 453, August 2001.

The same area, on RGB 321 composite (Landsat 7, ETM+), August 2001.

Dry forest physiognomy (April, 2004); note the person used as a scale reference. The average height varies between 15 and 25 meters. Most of the trees are erect, with some emergent. During the rainy season, the tops touch each other, generally attaining a canopy cover of between 70 to 95%.

Dry forest profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

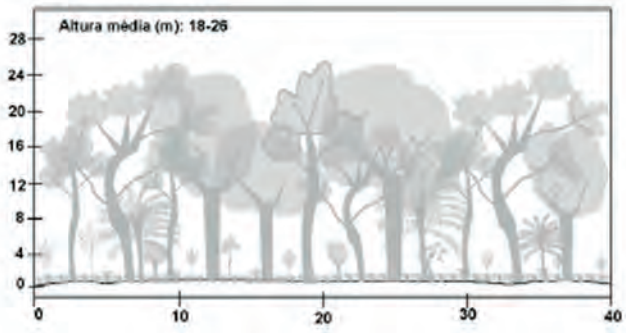
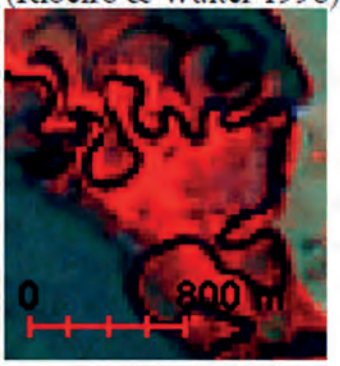
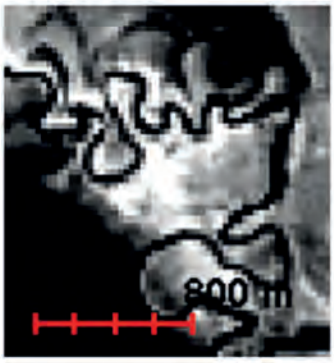


Figure 5 Relationship between the Landsat spectral signature and the land cover class Dry forest.

Riparian forest - spectral class included in the dense forest and riparian forest (gallery forest) type of Ribeiro & Walter (1998). Riparian forest is understood to be the forest vegetation that follows the medium and large dimensioned rivers of the Cerrado region, where the arborous vegetation does not form galleries. The forest width on each margin of the river is commonly equivalent to the river width, but can be greater in flat areas. However, the riparian forest usually occurs over irregular surfaces, with a gradual transition to other forest physiognomies such as dry forest and "cerradão" being possible (Ribeiro & Walter 1998).

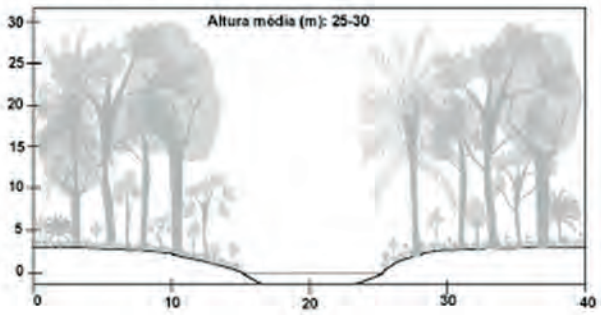


Riparian forest - Landsat 7, ETM+, false colour composition RGB 453, August 2001.



The same area in near infrared band (Landsat 7, ETM+), August 2001.

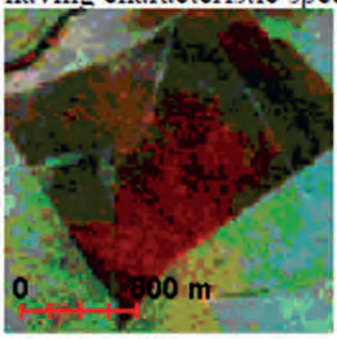
Trees are predominantly erect, varying from 20 to 25m in height, with some emergent elements reaching 30m or more. The typical species are predominantly deciduous, with some evergreens. During the year, the trees present an arborous cover of 50 to 90% (rarely more), being greatest during the rainy season.



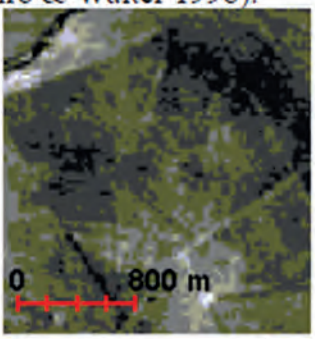
Riparian forest profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

Figure 6 Relationship between the Landsat spectral signature and the land cover class. Riparian forest.

Open forest - spectral class corresponding to "cerradão" and dry forests of Ribeiro & Walter (1998). It is characterized by the presence of forest species, and is less dense (less biomass) than Dry and Riparian forest. From the physiognomic point of the view, it is a forest, but, floristically, it is quite similar to a scrubland. According to soil fertility, the "cerradão" can be classified as dystrophic (poor soil) or mesotrophic (richer soil), each having characteristic species (references in Ribeiro & Walter 1998).



Open forest - Landsat 7, ETM+, false colour composition RGB 453, August 2001.



The same area in the near infrared band (Landsat 7, ETM+), August 2001.

The open forest presents a predominantly continuous canopy cover that may reach from 50 to 90%. The arboreal strata height ranges from 8 to 15m, allowing light conditions that permit the formation of differentiated shrub and herbaceous strata. Although perennial species may be present, many are common to the true cerrado class (see below), such as *Caryocar brasiliense, Kielmeyera coriacea* and *Qualea grandiflora,* and possess deciduous leaves.

Open forest physiognomy (April, 2004); note the person used as a scale reference.

Open forest profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

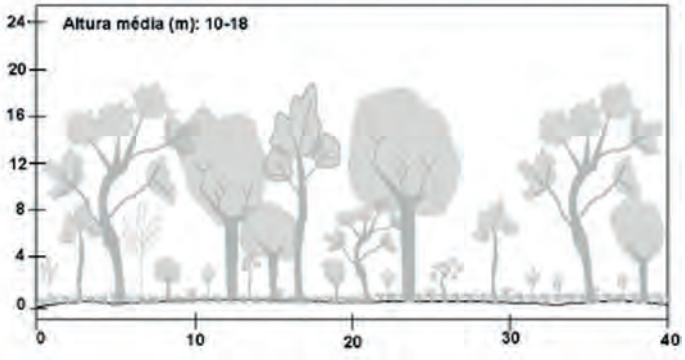
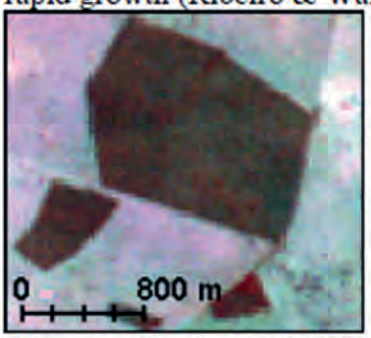
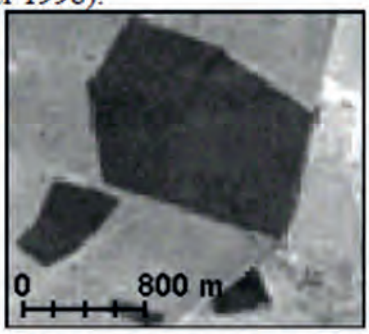


Figure 7 Relationship between the Landsat spectral signature and the land cover class Open forest.

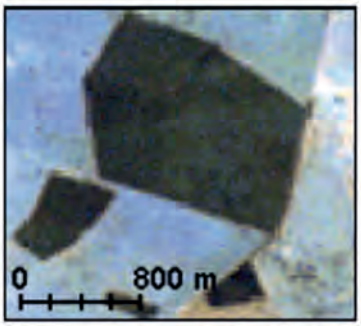
True cerrado - spectral class corresponding to the narrowly defined "cerrado" of Ribeiro & Walter (1998). It is characterized by the presence of low trees, inclined, tortuous, with irregular twisted ramifications, and generally with signs of fire. The shrubs are found scattered, with some species presenting perennial underground organs that permit sprouting after burning or cutting. In the rainy season, the herbaceous layers become exuberant due to rapid growth (Ribeiro & Walter 1998).



Cerrado – Landsat 7, ETM+, false colour composition RGB 453, August 2001.



The same area in false colour composition in band 7 (Landsat ETM+).



The same area in the RGB 752 combination (Landsat ETM+).

Distinct physiognomic sub-divisions have originated with regard to this class, with the principal being as follows: dense cerrado, typical cerrado, sparse cerrado, and rocky cerrado. The former three reflect variations in the formation of groups and spacing between woody individuals, with a decreasing gradient in abundance of the latter from dense to sparse cerrado. Rocky cerrado is distinguished by the substrate, typically with shallow soils and rock outcrops, and by having distinctive characteristic species (Ribeiro & Walter 1998). True cerrado has a quite deciduous character, tending to partially lose leaves during the dry season (Paranhos Filho, 2000), an important factor with regard to image identification.

True cerrado physiognomy (April, 2004); note the person used as a scale reference.

Dense cerrado profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

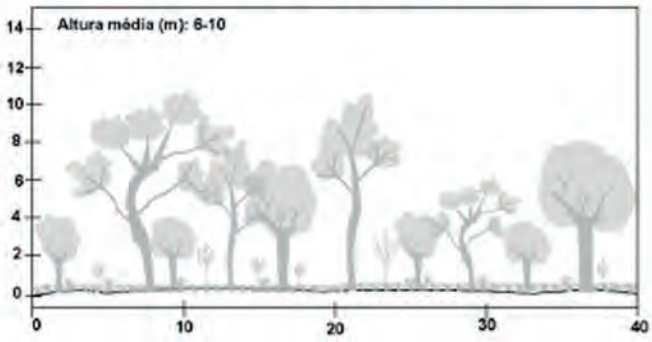
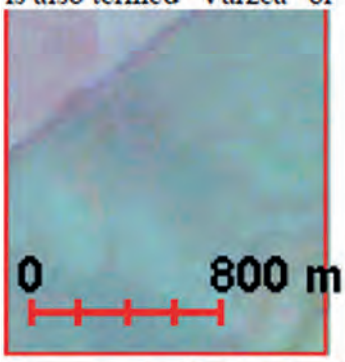
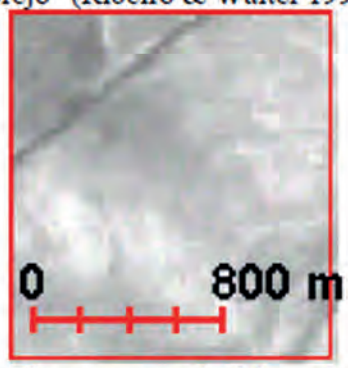


Figure 8 Relationship between the Landsat spectral signature and the land cover class True cerrado.

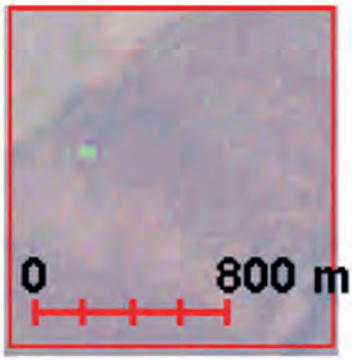
Open grassland - spectral class corresponding to the "campo limpo" of Ribeiro & Walter (1998). It has a predominantly herbaceous physiognomy, with rare occurrence of shrubs and an absence of trees (both of the latter often removed to create areas for cattle grazing). This vegetation can been found in diverse topographical positions, with variations in the degrees of soil humidity, depth and fertility. However, open grassland is most often encountered on slopes, hills, around springs, and bordering riparian woodlands. When present on flat, relatively extensive areas, adjacent to rivers and periodically flooded, this type of vegetation is also termed "Várzea" or "Brejo" (Ribeiro & Walter 1998).



Open grassland - Landsat 7, sensor ETM+, false colour composition RGB 453.



The same area in false colour composition in band 7 (Landsat ETM+).



The same area in combination RGB 321 (Landsat ETM+).

Open grassland presents variations, each with a specific flora, related to soil humidity and topography. In the presence of a deep water table, dry grassland occurs, while humid grassland occurs when the water table is shallow (see below). When present on small hills ("murunduns"), the type is termed murundun grassland (Ribeiro & Walter 1998).

Open grassland physiognomy (November 2003).

Open grassland profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

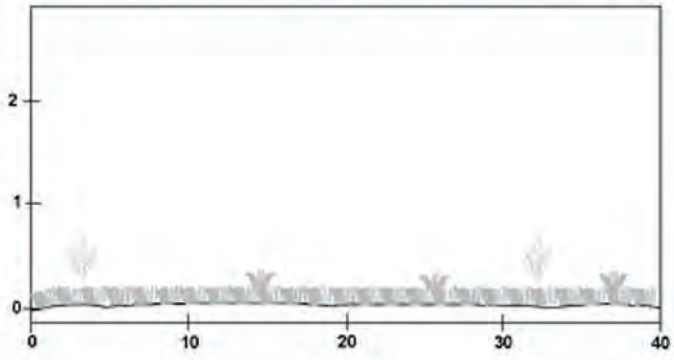
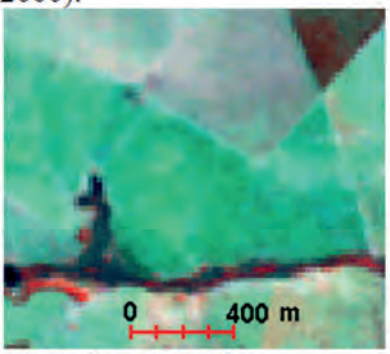


Figure 9 Relationship between the Landsat spectral signature and the land cover class Open grassland.

Dry/tall grassland – a type of open grassland. This vegetation is taller (more than 40 cm in height) than Open grassland (Plate 7), with possible occurrence of dry shrubs (Paranhos Filho, 2000).

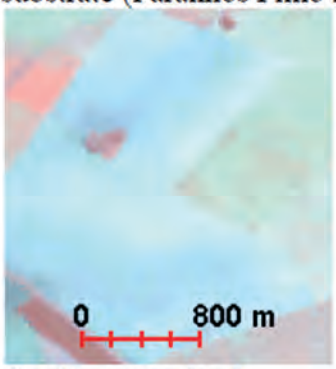


Dry/tall grassland physiognomy of approximately 40 - 60 cm in height (April 2004).

Dry/tall grassland - Landsat 7 (sensor ETM+) orbit 224 point 073, in green, composition R4 G5 B3 (August 2001).

Figure 10 Relationship between the Landsat spectral signature and the land cover class Dry/tall grassland.

Dry/low grassland – a type of open grassland. This type is lower and drier (generally trampled and degraded) than that shown in plate 8. In the images of this class (compositions 457 and 453, Landsat TM), the paler the colour, the lower is the vegetation and the more visible is the substrate (Paranhos Filho 2000).



Dry/low grassland physiognomy.

Dry/low grassland - in Landsat 7 (sensor ETM+) orbit 224 point 073, composition R4 G5 B3, August 2001.

Figure 11 Relationship between the Landsat spectral signature and the land cover class Dry/low grassland.

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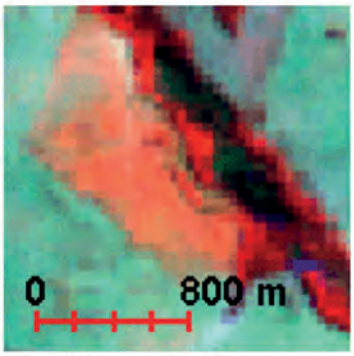
Humid grassland – type of open grassland possessing, throughout the year, a greener colour than the previous types.

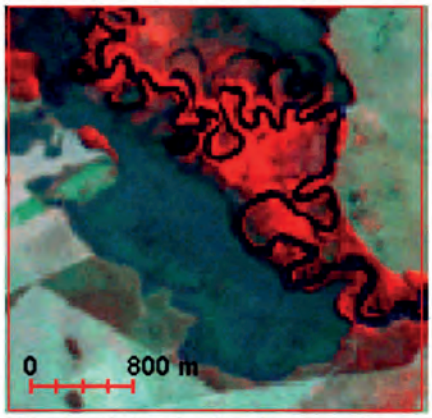


Humid grassland physiognomy (November 2003).

Humid grassland - Landsat 7 (sensor ETM+) orbit 224 point 073, in orange in the composition R4 G5 B3, August 2001.

Figure 12 Relationship between the Landsat spectral signature and the land cover class Humid grassland.

Wetland - (Paranhos Filho 2000).

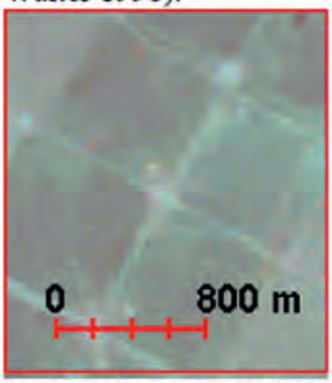


Wetland. In the background, a palm swamp (April 2004).

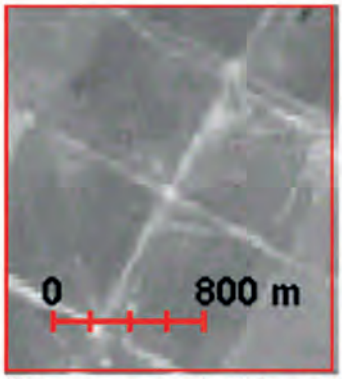
Wetland in Landsat 7 (sensor ETM+) orbit 224 point 073, in the composition R4 G5 B3 (August 2001).

Figure 13 Relationship between the Landsat spectral signature and the land cover class Wetland.

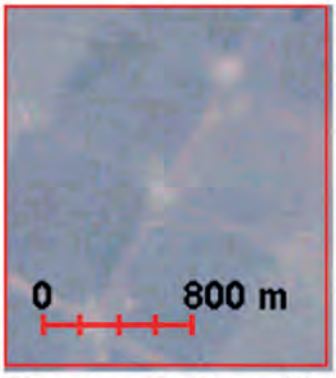
Scrubland - spectral class corresponding to the "campo sujo" of Ribeiro & Walter (1998). It is an exclusively herbaceous-shrub physiognomic type, with sparse shrubs, the individuals of which are frequently made up of less developed shrub species of the true cerrado (Ribeiro & Walter 1998).



Landsat 7, sensor ETM+, false colour composition RGB 453, August 2001.



The same area in false colour composition in band 7 (Landsat ETM+).



The same area in combination RGB 321 (Landsat ETM+).

Scrubland presents three distinct physiognomic sub-types. In the presence of a deep water table, dry scrubland occurs, while humid scrubland occurs when the water table is shallow. When present on hills, the type is termed murundun scrubland (Ribeiro & Walter 1998).

Scrubland physiognomy (November 2003).

Scrubland profile sketch representing a 40m long tract (Gamarra 2004, adapted from Ribeiro & Walter 1998).

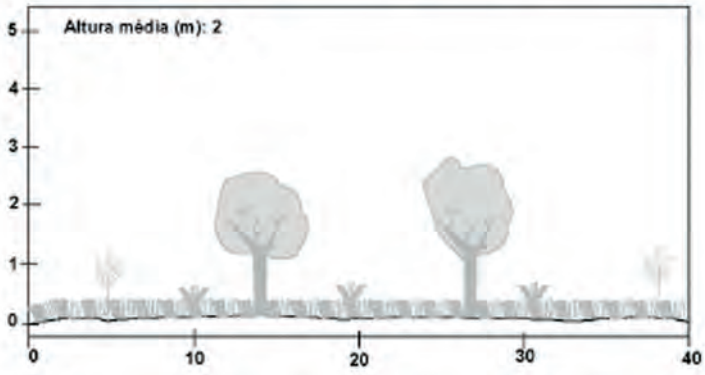
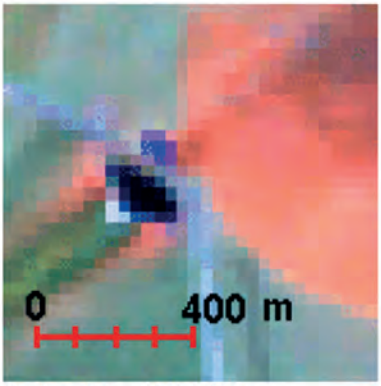


Figure 14 Relationship between the Landsat spectral signature and the land cover class Scrubland.

Lakes and other lentic water-bodies - (Paranhos Filho 2000).

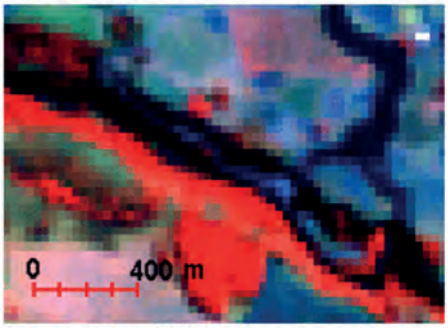


Lake (April 2004).

Lakes and other lentic water-bodies in Landsat 7 (sensor ETM+) orbit 224 point 073, in black in the composite R4 G5 B3 (August 2001).

Figure 15 Relationship between the Landsat spectral signature and the land cover class Lakes and other lentic water-bodies.

River - (Paranhos Filho 2000).



River (April 2004).

River in Landsat 7 (sensor ETM+) orbit 224 point 073, in dark blue tending towards black, in the composition R4 G5 B3, August 2001.

Figure 16 Relationship between the Landsat spectral signature and the land cover class River.

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